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OBJECT-ORIENTED DESIGN AND SPECIFICATION

For the period 1 October 1991 through 30 September 1992

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SRI Project ECU 8844

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1 Productivity Measures

Principal Investigator Name: José Meseguer
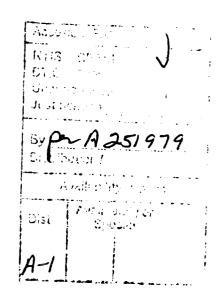PI Institution: CS Lab, SRI International
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Contract Title: Object-Oriented Design and Specification
Contract Number: N00014-90-C-0086
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- Refereed papers submitted but not yet published: 3

- Refereed papers published: 4

- Unrefereed reports and articles: 0

- Books or parts thereof submitted but not yet published: 2

- Books or parts thereof published: 0

- Patents filed but not yet granted: 0

- Patents granted: 0

- Invited presentations: 8

- Contributed presentations: 1

- Honors received[1]: 9

- Prizes or awards received: 0

- Promotions obtained: 0

- Graduate students supported: 0

- Post-docs supported: 1

- Minorities supported: 0

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[1]A description of these honors is included in Section 3.

2 Detailed Summary of Technical Progress

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We have made substantial progress in the following areas:

- The OBJ language

- Concurrent object-oriented programming and the Maude language

- Massive parallelism for declarative languages

- Computability of algebraic data types

2.1 OBJ

After completing release 2.0 of the OBJ3 system—which is several times faster than the previous version, has new and more efficient algorithms for matching modulo axioms, and has new features useful in theorem-proving applications—our main effort has focused on providing the large community of OBJ3 users (now including researchers and students in over 100 universities and research laboratories worldwide) with a comprehensive and gentle introduction to all the aspects of OBJ, including its detailed syntax and its mathematical and operational semantics; its modularity, parameterization, and theorem-proving features; its use and the use of built-in modules; and many examples and applications to areas such as rapid prototyping, formal definition of programming languages, theorem-proving and program verification, and computational algebra. This introduction [2] is a fairly extensive monograph (110 pages) that currently provides the best documentation of the OBJ3 system; it will appear as a chapter in a forthcoming book on uses of and experiences with OBJ.

The paper [9] by Winkler serves the complementary purpose of providing a briefer first introduction with examples to OBJ3 for a wider circle of readers who may not be users of OBJ and of discussing additional topics on the semantics of OBJ in a novel way. The paper also provides a brief sketch with examples of the Maude language (more on Maude in Section 2.2), illustrating how it extends OBJ in important ways.

2.2 Maude and Concurrent Object-Oriented Programming

Maude is a declarative language that unifies functional programming, concurrent object-oriented programming, and general concurrent systems programming. Maude is based on a simple logic of action called *rewriting logic* whose models are concurrent systems and whose deduction is concurrent computation in such systems.

Rewriting logic's rules of deduction, model theory, and soundness and completeness theorems, as well as its use as a very general model of concurrency, have been published in [3].

A detailed study of Maude's concurrent object-oriented facet and of how the basic concepts of object-oriented programming can be naturally expressed in rewriting logic in a fully declarative way is presented and is illustrated with examples in the paper [4].

The paper [5] presents a general axiomatic notion of "logic programming language" based on the previous work of Meseguer on General Logics[2] and discusses methods for defining multiparadigm logic programming languages. The Maude and MaudeLog languages are viewed as specific examples of a multiparadigm logic programming language satisfying the general requirements proposed in the paper and unifying functional programming, concurrent object-oriented programming, and (in MaudeLog's case) Horn logic programming.

The paper [6] by Meseguer, Futatsugi, and Winkler gives an overview of Maude and rewriting logic with special emphasis on the software technology innovations made possible by this approach, including concurrency and machine independence, declarativeness and wide-spectrum capabilities, multiparadigm nature, highly reusable and adaptable modules, and suport for decentralized cooperative problem solving.

2.3 Massive Parallelism for Declarative Languages

Concurrent rewriting, the model formalized as logical deduction by rewriting logic [3], directly supports parallel programming in very high-level declarative languages. The Rewrite Rule Machine (RRM) is a massively parallel computer that physically realizes the concurrent rewriting model. The RRM is hierarchical, with SIMD computation performed at the chip level, called an *ensemble*, but with the machine as a whole, consisting of many ensemble chips, working in MIMD mode. The paper [1] by Aida, Goguen, Leinwand, Lincoln, Meseguer, Taheri, and Winkler gives an overview of the RRM's architecture and presents performance studies based on benchmarks run on a very detailed simulator, modeling based on those simulations, and comparisons with sequential executions.

The paper [7] by Meseguer and Winkler treats the related subject of Maude's parallel programming capabilities. The emphasis is on the machine-independent nature of a sublanguage called Simple Maude that can be implemented on a wide variety of parallel architectures, including SIMD, MIMD, and (as it is the case for the RRM) architectures that combine SIMD and MIMD computation.

2.4 Computability of Algebraic Data Types

The paper [8] by Moss, Meseguer, and Goguen is the published full version of the author's previous work on computability of algebraic data types specified by final algebra semantics. In essence, it is shown that any co-r.e. behavior is finitely specifiable by an abstract data type specified by final algebra semantics. Also, the set of congruences of finitely generated free algebras is studied, giving necessary and sufficient conditions for the cases when this set is countable or has the cardinality of the continuum. Degrees of unsolvability are also studied, and it is shown how they can be realized by initial and final algebra specifications.

3 List of Publications, Presentations, Reports and Awards/Honors

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3.1 Publications and Reports

References

[1] H. Aida, J. Goguen, S. Leinwand, P. Lincoln, J. Meseguer, B. Taheri, and T. Winkler. Simulation and performance estimation for the rewrite rule machine. To appear in *Proc. 4th Symp. on Frontiers of Massively Parallel Computation*, McLean, Virginia, October 1992, 1992.

[2] Joseph Goguen, Timothy Winkler, José Meseguer, Kokichi Futatsugi, and Jean-Pierre Jouannaud. Introducing OBJ. Technical Report SRI-CSL-92-03, SRI International, Computer Science Laboratory, 1992. To appear in J.A. Goguen, editor, *Applications of Algebraic Specification Using OBJ*, Cambridge University Press.

[3] José Meseguer. Conditional rewriting logic as a unified model of concurrency. *Theoretical Computer Science*, 96(1):73-155, 1992. Also Technical Report SRI-CSL-91-05, SRI International, Computer Science Laboratory, February 1991.

[4] José Meseguer. A logical theory of concurrent objects and its realization in the Maude language. To appear in G. Agha, P. Wegner, and A. Yonezawa (eds.) *Research Directions in Object-Based Concurrency*, 1992.

[5] José Meseguer. Multiparadigm logic programming. In H. Kirchner and G. Levi, editors, *Proc. 3rd Intl. Conf. on Algebraic and Logic Programming*, pages 158–200. Springer LNCS 632, 1992.

[6] José Meseguer, Kokichi Futatsugi, and Timothy Winkler. Using rewriting logic to specify, program, integrate, and reuse open concurrent systems of cooperating agents. To appear in Proceedings of the 1992 International Symposium on New Models for Software Architecture, Tokyo, Japan, November 1992, 1992.

[7] José Meseguer and Timothy Winkler. Parallel Programming in Maude. In J.-P. Banâtre and D. Le Métayer, editors, *Research Directions in High-level Parallel Programming Languages*, pages 253–293. Springer LNCS 574, 1992. Also Technical Report SRI-CSL-91-08, SRI International, Computer Science Laboratory, November 1991.

[8] L. Moss, J. Meseguer, and J.A. Goguen. Final algebras, cosemicomputable algebras, and degrees of unsolvability. *Theoretical Computer Science*, 100:267–302, 1992.

[9] Timothy Winkler. Programming in OBJ and Maude. To appear in Peter Lauer, ed., Springer LNCS, 1992.

3.2 Presentations

The following is a list of lectures given at professional conferences and seminars during the last academic year:

1. Lecture by J. Meseguer on "Maude and the Rewrite Rule Machine" at the California Institute of Technology, Pasadena, California, October 1991.

2. Lecture by J. Meseguer on "Declarative Programming" at the Center for the Study of Language and Information, Stanford University, Stanford, California, November 1991.

3. Lecture by J. Meseguer on "Parallel Programming in Maude" at the Kestrel Institute, Palo Alto, California, March 1992.

4. Lecture by J. Meseguer on "Parallel Programming in Maude" at the University of Pisa, Italy, May 1992.

5. Lecture by J. Meseguer on "Maude and the Rewrite Rule Machine" at the University of Southern California, Los Angeles, California, June 1992.

6. Lecture by J. Meseguer on "Maude and the Rewrite Rule Machine" at the Supercomputer Research Center, Bowie, Maryland, June 1992.

7. Lecture by J. Meseguer on "Maude and the Rewrite Rule Machine" at the Hewlett-Packard Research Laboratories, Palo Alto, California, July 1992.

8. Lecture by V. Sassone on the paper "On the Semantics of Petri Nets" by Meseguer, Montanari and Sassone at the CONCUR'92 International Conference, Stony Brook, New York, August 1992.

9. Invited Lecture by J. Meseguer on "Multiparadigm Logic Programming" at the Algebraic and Logic Programming International Symposium, Volterra, Italy, September 1992.

3.3 Awards/Honors

1. Editorial board of the Journal on Mathematical Structures in Computer Science (J. Meseguer).

2. Member of the IFIP Working Group 14.3 (Foundations of Systems Specification) (J. Meseguer).

3. Member of the GI (Gesellschaft fuer Informatik) Working Group 0.1.7 (Specification and Semantics) (J. Meseguer).

4. Program Committee of LICS'93 (Symposium on Logic in Computer Science) to be held in Montreal, Canada, June 1993 (J. Meseguer).

5. Program Committee of the Daghstuhl Workshop on Specification and Semantics to be held in Daghstuhl Castle, Germany, May 1993 (J. Meseguer).

6. Visiting Professor, holding the BBV Foundation Chair, University of Navarre, Spain, Fall 1992 (J. Meseguer).

7. Invited Lecture on "Multiparadigm Logic Programming" at the Algebraic and Logic Programming International Symposium, Volterra, Italy, September 1992 (J. Meseguer).

8. Session Chairman at the Algebraic and Logic Programming International Symposium, Volterra, Italy, September 1992 (J. Meseguer).

9. Invited lecture on "Using Rewriting Logic to Specify, Program, Integrate, and Reuse Open Concurrent Systems of Cooperating Agents" at the Second International Symposium on New Models for Software Architecture, Tokyo. Japan, November 1992 (J. Meseguer).

4 Transitions and DOD Interactions

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The OBJ3 2.0 release has many improvements and new features extending substantially the uses that can be made of the system in formal methods applications in addition to its uses for experimental programming and rapid prototyping. The system is well documented by a collection of technical publications and by a detailed language manual with many examples. The system is now used by many researchers and students in over 100 universities, research laboratories, and industrial sites around the world. In addition, an electronic OBJ forum is now administered at Oxford University, OBJ users meetings are held from time to time, and additional implementation efforts are ongoing in Britain, France, Italy, and Japan.

Besides transitioning the ideas by means of their embodiment in software systems, the researchers in the project are also making a serious effort to transmit them to the research community through publications, lectures, and courses, as summarized in this report.

Fruitful interactions related to the Navy during the last academic year include:

- Technical discussions with Dr. Ralph Wachter, of the Office of Naval Research, in March and June 1992, on the research conducted under this contract and under contract N00014-88-C-0618

- Technical discussions with Dr. Keith Bromley, of the Naval Ocean Systems Center, in June 1992, on research conducted under a separate ONR contract on the Rewrite Rule Machine

In addition, the project leader has engaged in a variety of technical discussions with research officers at other DOD agencies, including DARPA, SDIO, and NSA.

5   Software and Harware Prototypes

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Researchers and students in over 100 universities and research and industrial institutions are users of the OBJ3 system. The system, as well as extensive documentation for its use and for understanding its scientific basis, can be obtained from SRI International for a nominal distribution fee. The OBJ3 release 2.0 has increased performance and supports theorem-proving applications by means of a variety of new language features; this broadens the number of software engineering and formal methods applications to which OBJ3 can be applied.